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Observation of induced phonons by ZnO transducer with coaxial microwave resonator using Brillouin scattering

Brillouin 散乱法による同軸マイクロ波共振器を用いた ZnO 薄膜からの励起フォノンの観測

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1. Introduction

Brillouin scattering is a nondestructive technique to measure sound velocity propagated in thin material, using a focused laser beam. This technique enables the evaluation of longitudinal and shear wave velocities in the microscopic region at hypersonic frequencies. However, the measurement accuracy of wave velocities is lower than those of other methods, such as ultrasonic pulse techniques. The accuracy strongly depends on the measurement condition and transparency of the sample, because Brillouin scattering from the thermal phonons is usually weak.

We have then tried to overcome this problem making use of the induced longitudinal and shear acoustic phonons excited by ZnO film transducer.[1] To simplify the measurement system, we here report on the use of a coaxial resonator to excite the acoustic phonons without using electrodes. This method make it possible to generate electric field in the piezoelectric film with noncontact.

2. Measurement system

Brillouin scattering measurements were performed by a six-pass tandem Fabry-Pérot interferometer (JRS scientific instruments) using an Argon ion laser at a wavelength of 514.5 nm. The actual diameter of the focused laser beam in the sample was approximately 50 µm. The laser power near the sample was 60 mW.

In this measurement, the wavelength and the direction of the observed phonons are determined by the scattering geometry, which specifies the directions of the incident and scattered lights. In this study, we used the Reflection Induced ΘA (RIΘA) scattering geometry in **Fig. 1**.[2] This geometry is attained by attaching a flat metal film to the reverse side of the samples as a reflector, and enables the simultaneous measurement of phonons that propagate in both wave-vectors of $\boldsymbol{q}^{\Theta A}$ and $\boldsymbol{q}^{180}$. We then focused on $\boldsymbol{q}^{\Theta A}$ propagating in-plane. From the spectrum, we can obtain the frequency shift $f^{\Theta A}$, which gives us the wave velocity by the following equation.

$$V^{\Theta A} = f^{\Theta A}\frac{\lambda_i}{2\sin \Theta/2} \qquad (1)$$

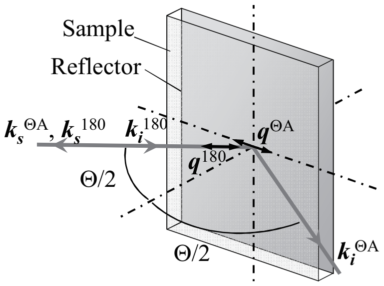

Fig. 1 RIΘA scattering geometry: $\boldsymbol{k}_i$ is the wave vector of incident light, $\boldsymbol{k}_s$ is the wave vector of scattered light, and $\boldsymbol{q}$ is the wave vector of the sound wave. Θ/2 is the angle between incident laser beam and normal line of sample surface.

Here, λ_i is the wavelength of the incident light. Equation (1) shows that the shift frequency $f^{\Theta A}$ changes due to the incident angle Θ/2.

3. Measurement sample

Figure 2 shows the sample configuration. In this study, we have attempted to observe induced shear and longitudinal acoustic phonons in a silica glass sample (Tosoh, ED-B, 3×10×35 mm^3), using the ZnO piezoelectric film developed in our laboratory.[3] The crystalline c-axis of this film tilted to substrate normal, and this allows us to excite both shear and longitudinal wave in the GHz range. The film was deposited on one side of the silica glass sample. On the reverse side of the sample, an aluminum film was deposited as a light reflector.

We used signal generator (E8257D, Agilent technologies) and the coaxial resonator (AET, Inc.) to induce sound wave. We applied the electric field to the ZnO film using the electromagnetic evanescent wave that leaked from small orifice placed the resonator. In this technique, we were able to input electric field to a small region of the ZnO film without electrodes.

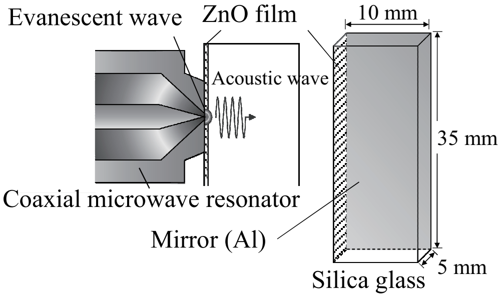

Fig. 2 The sample configuration.

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4. Results and discussion

Figure 3 (a) shows a Brillouin spectrum from the silica glass sample without the induced shear wave. A pair of peaks due to the shear acoustic phonon is observed at 2 GHz. Here, we chose Θ/2=7.8 °. At this angle, the frequency shift $f^{\Theta A}$ (shear acoustic phonons) is near the first resonance frequency of coaxial resonator. **Figure 3 (b)** shows the Brillouin spectrum from the sample with induced shear wave. The Stokes peak is strongly amplified. This result corresponds with the propagation direction of the induced wave. The Stokes peak intensity is approximately 37000 counts (applied power P_{sw} to coaxial resonator is 34 dBm). In contrast, the anti-Stokes peak due to thermal phonons is approximetely 40 counts. **Figure 3 (c)** shows the Brillouin spectrum from the sample with induced longitudinal wave. Here, we chose Θ/2=4.9 °. At this angle, the frequency shift $f^{\Theta A}$ (longitudinal acoustic phonons) is near the first resonance frequency of coaxial resonator. The Stokes peak is strongly amplified. The Stokes peak intensity is approximately 40000 counts (applied power P_{sw} to coaxial resonator is 20 dBm). In contrast, the anti-Stokes peak is approximetely 110 counts.

Figure 4 shows the light intensity distribution in a silica glass sample. The light intensity decreses as a function of distance from the ZnO film. Curved lines represent estimated values of attenuation in the silica glass sample. The curved lines for 81 dB/cm (shear) and 38 dB/cm (longitudinal) were obtained from the estimated value of propagation loss at 2 GHz[4][5]. The distribution of the light intensity is almost in agreement with the estimated value.

5. Conclusion

We have succeeded in the Brillouin scattering measurement of longitudinal and shear acoustic waves induced by ZnO thin film. Moreover, the sound wave was able to be induced easily by using a coaxial resonator without electrodes. This technique can improve the measurement accuracy and shorten the measurement time.

References

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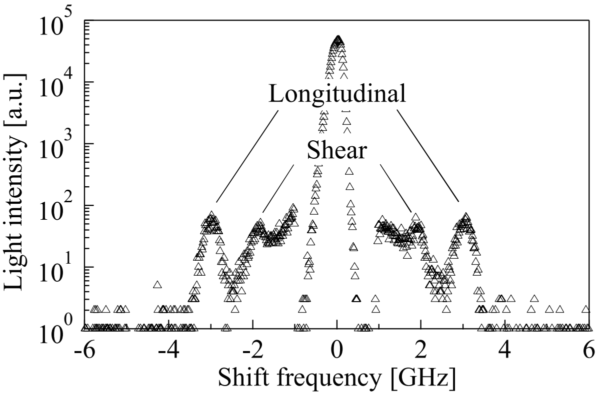
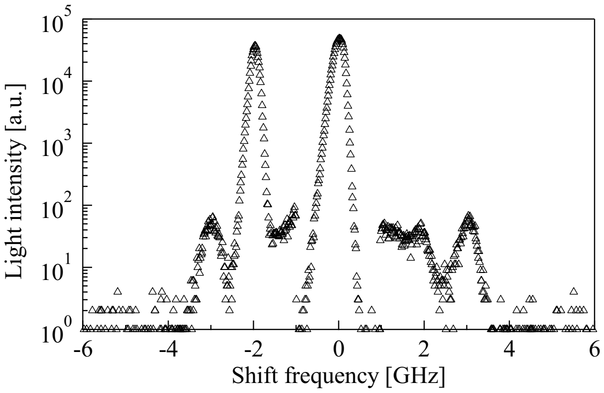
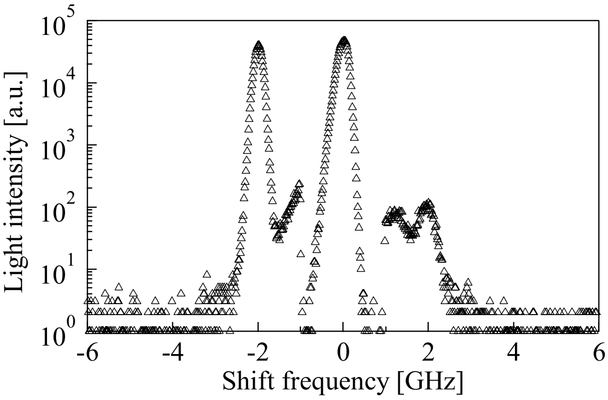


(a) Without the induced shear wave.
(Θ/2=7.8 °)



(b) With the induced shear wave.
(Θ/2=7.8 °, f_{sw}= 1.987 GHz)



(c) With the induced longitudinal wave.
(Θ/2=4.9 °, f_{lw}= 1.983 GHz)

Fig. 3 Brillouin spectrum in the silica glass.

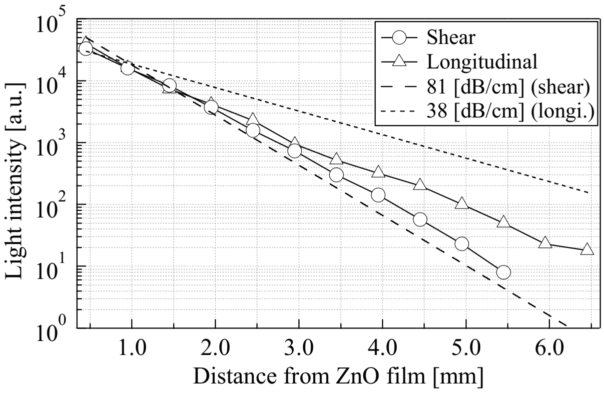


Fig. 4 Attenuation characteristics.